Shelfbreak PRIMER Data Analysis: Acoustic Propagation And Ocean Tomography

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LONG-TERM GOAL

My long-term research goals are:

1. To understand the effects of meso to internal-wave-scale oceanographic processes on broadband sound transmissions in a coastal environment. Central to the understanding are the formulation of accurate forward relations and the quantification of the sensitivities and variability of the various acoustic quantities in relation to environmental differences and changes.
2. To develop high-resolution tomographic inverse techniques to measure the dynamics and kinematics of meso and finer-scale sound speed structure and ocean currents in coastal regions.

OBJECTIVES

The field work of the Shelfbreak PRIMER field study was completed in FY97. The data analysis phase of the experiment began in FY98. In collaboration with investigators (Lynch et al.) from the Woods Hole Oceanographic Institution, our objectives are to address the following acoustic and oceanographic issues through follow-on data analysis and modeling:

1. To determine the effects of seasonal and mesoscale variability of the shelf-break frontal thermal structure on the transmission of sound from the fixed sources on the slope to the vertical line hydrophone arrays (VLAs) on the shelf.
2. To relate the temporal and spatial variability of the acoustic propagation with the ocean variability in the frontal zone.
3. To obtain tomographic maps of the frontal region for use in the physical oceanographic description.
4. To investigate plausible hypotheses of shelfbreak frontal dynamics using a combination of acoustic tomography, SeaSoar, thermistor-string, ADCP and current-meter data.

APPROACH

The experimental approach involves detailed and simultaneous measurements of physical oceanographic and acoustic properties during the contrasting summer and winter seasons. These measurements are being related to physical and acoustical modeling studies.

In the acoustic propagation analysis, the focus of the Naval Postgraduate School (NPS) effort is on the repeated transmissions of a pulse signal from the moored sources on the slope to the NW VLA (i.e., one of the two VLAs) on the shelf. The NPS analysis entails resolving the arrivals of individual modes

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using an adaptive modal beamforming technique (Chiu et al., 1997 and Miller, 1998), and modeling the arrival structure and its variability in time using the coupled-mode propagation model of Chiu et al. (1996). Input to the model are continuous ocean fields analyzed from high-resolution hydrographic measurements. The modeling results are compared to the observed modal arrivals for the quantification of the fluctuations in the intrinsic acoustic variables such as magnitudes, phases, arrival times and mode patterns, and how these acoustic fluctuations are related to the shelf-slope ocean processes.

The inverse tomographic analysis requires a new inverse method that can properly handle the severe environmental gradients near the shelfbreak. Based on modal physics, an inverse method accounting for strong mode coupling is developed to map the structure of the shelfbreak front and the associated frontal variability at a fast sampling rate. In addition to the purely acoustic approach, inverse analysis that combines different types of data and constrained by plausible frontal dynamics will be applied. Because the nature of the tomographic data is quite different (integral as oppose to point), combining the complementary tomographic data with SeaSoar, thermistor-string, ADCP and current-meter data in dynamically-constrained, joint inversions can provide for a powerful means of testing different theories and hypotheses.

WORK COMPLETED

Work completed in FY99 includes:

1. Examined the relations of the observed summertime variability in the magnitudes and travel times of acoustic modes to the observed summertime ocean variability in the frontal zone using spectral and correlation techniques.
2. Developed a new modal technique to invert the observed travel times of strongly coupled acoustic modes. This new technique replaces the previous method which assumes weak coupling.
3. Updated the summertime tomographic maps of the frontal region using the refined technique.
4. Processed the winter NW VLA data to obtain time-series of the arrivals of individual modes.

RESULTS

Based on the stepwise coupled-mode sound-pressure solution presented by Jin et al. (1996) for a shelf-slope environment, a new inverse scheme that can properly handle strong mode coupling was formulated. The formulation divides the ocean into many thin vertical sections. Within each section both the background sound speed and sound speed changes are taken to be horizontally homogeneous. This nicely compartmentalizes the mode propagation physics into a range-history of independent evolution inside each of the thin sections and a range-history of coupling at each of the interfaces. With the forward solution expressed in this form, a variation in the modal travel time can be cast as a function of the evolution history and coupling history associated with the “background” ocean and changes in these histories due to sound speed changes. The inversion of the modal travel times was accomplished using least-squares estimations. When the changes in the coupling history are negligible, the inverse solution reduces to a linear estimate. However, when the changes in the coupling history are not negligible, the estimation becomes a nonlinear minimization problem, significantly increasing computational time. Two of the tomographic maps are displayed in Fig. 1, showing the intrusion of a warm filament into the shelfbreak followed by its retreat and a seaward extension of the cold front.

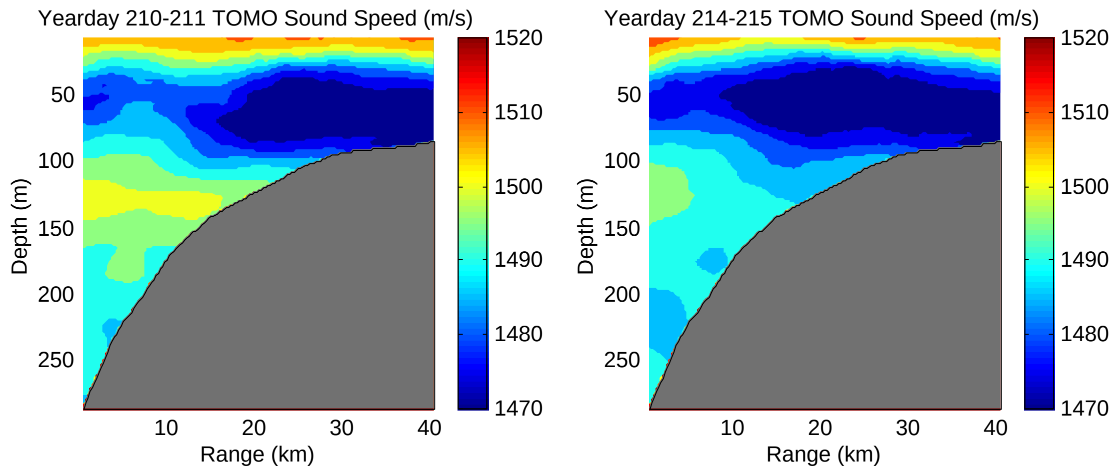

Figure 1. Tomographic maps of cross front sound speed for Yearday 210-211 and Yearday 214-215, respectively.

Spectral estimation and correlation analysis were performed to study the variances of the modal amplitudes and travel times and their relations to the ocean variability in different frequency bands. For this report, we shall limit our discussion to the fluctuations in the synoptic (> 1 cycle per day) and tidal (approximately from 1/2 to 1 cycle per day) bands. In these bands and based on a combined analysis of the in situ oceanographic data, infrared satellite imagery and tomographic maps, it is conclusive that the environmental conditions along the NW track were dominated by a meandering cold front, a warm filament that was remnant of a dissipating core ring, and internal tides. While the intruding warm filament contributed significantly to the ocean variability seaward from the shelfbreak, the internal tides dominated the variability shoreward from the shelfbreak including the shelfbreak. The meander gradually moved the cold shelf water seaward and affected the ocean temperature over all three locales, i.e., the slope, shelfbreak and shelf.

In Figure 2, we show the measured temperature variations in the thermocline at these three distinctive locales and the measured amplitude and travel time fluctuations of the lowest five modes at 400 Hz, respectively. Furthermore, the correlation of the modal amplitude and travel-time fluctuations to the temperature variations at the three locales are summarized in Table 1. At the synoptic scale, the modal amplitude fluctuations are highly correlated to the slope processes and less correlated to the shelf and shelfbreak processes. This implies that the amplitude fluctuations were largely related to changes in the source-excitation function and mode-coupling activities on the slope as a result of the advection of both cold and warm water masses. Unlike the modal amplitudes, the synoptic-scale fluctuations in the travel time are almost equally correlated to the temperature variations at the different locales. This is attributed to the integrating nature of the travel times. At the tidal band, both the modal magnitudes and travel times are more correlated to the tidal variability at the shelfbreak as the tidal temperature variance was significantly larger near the shelfbreak than on the shelf and slope.

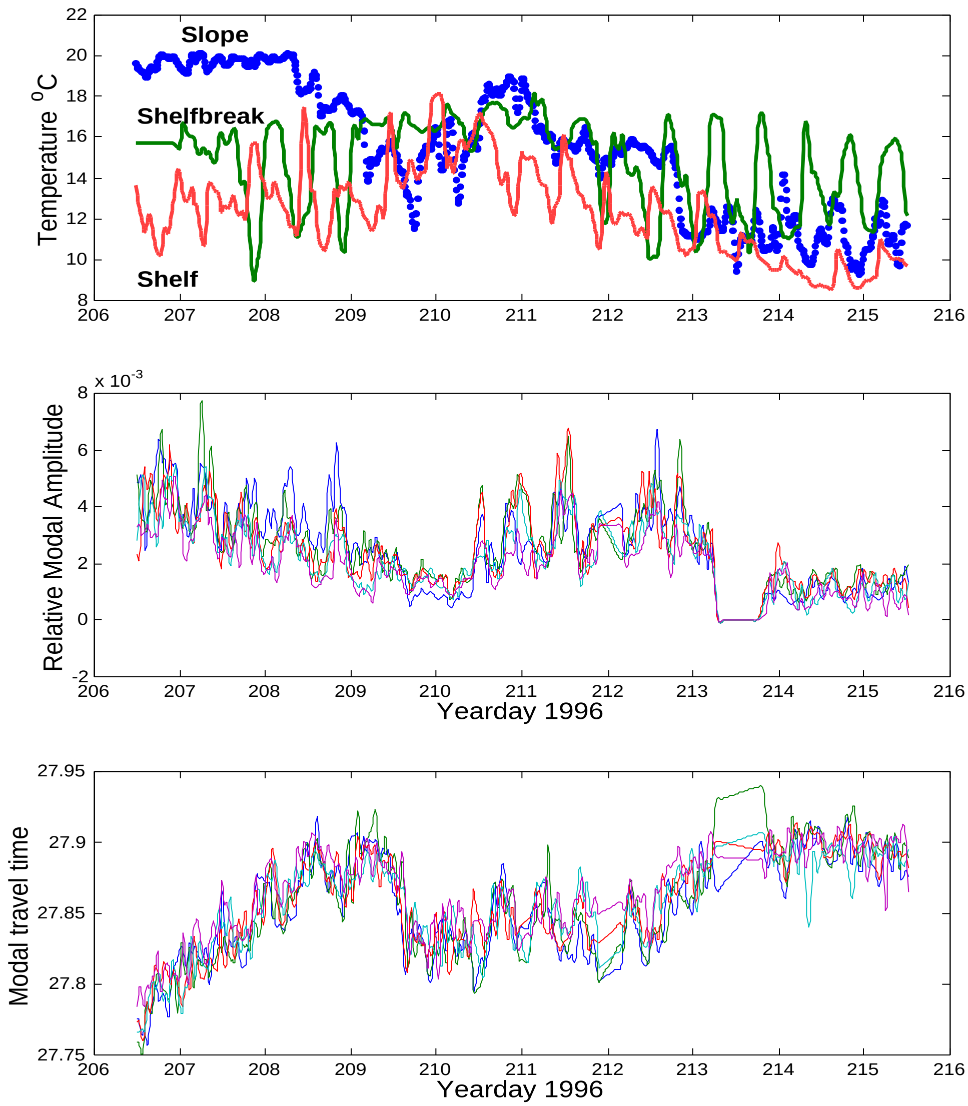

Figure 2. Measured thermocline temperature variability on the slope, shelfbreak and shelf (upper panel), and measured amplitude fluctuations (middle panel) and travel time fluctuations (lower panel) of the lowest five modes at 400 Hz.

Temperature Variations	Modal Amplitude Fluctuations		Modal Travel Time Fluctuations	
	Synoptic Band	Tidal Band	Synoptic Band	Tidal Band
Slope	0.8	0.1	-0.7	0.0
Shelfbreak	0.3	-0.3	-0.6	0.4
Shelf	0.4	0.0	-0.6	-0.1

Table 1. Cross-correlation (coefficient) between measured modal amplitude and travel time fluctuations and the measured temperature variability in the thermocline of the slope, shelfbreak and shelf regions, respectively.

IMPACT/APPLICATIONS

The oceanographic data gathered in this field study should be valuable in helping to create a general environmental model of shelfbreak regions suitable for assessing present and future Navy systems, acoustic as well as non-acoustic. In conjunction with the oceanographic data, the acoustic data will allow for an in-depth understanding of the coherence of the sound field in a shelf-slope environment, as well as for validating tomography as a useful tool for coastal monitoring.

TRANSITIONS

This program is combined with 6.2 efforts in ocean data assimilation/nowcasting and acoustic prediction in a vertically integrated fashion, so that the transition to higher levels and systems should be facilitated.

RELATED PROJECT

This project strongly compliments a number of other current projects including two other PRIMER experiments (Haro Strait and the CMO high frequency) and the SWARM experiment, which study different aspects of the coastal ocean variability and the relations to coastal acoustic fluctuations. Additionally, scientific insight gained from Shelfbreak PRIMER will be used to guide the experimental design and data analysis for the upcoming international ASIAEX experiment.

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